The Galactic System.[1]

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II.

IN the first part of this article the main characteristics of the globular and open clusters were discussed, and it was shown how the determination of their distances led to the proposal of extremely great dimensions for the galactic system. A theory of the origin and structure of the Galaxy also seems to be indicated by the observations.

OBJECTIONS TO PROPOSED SCALE OF THE GALAXY.

Although the new values of galactic dimensions have been widely accepted by astronomers, at least qualitatively, they have been openly challenged by some. Without questioning my values (which may indeed have been unknown to him), Prof. Charlier published a few years ago provisional cluster distances that are of a wholly different order of magnitude from those I derive.[8] He had, in effect, affiliated the globular clusters with the local system of B stars. I believe he has now accepted the larger values of the distances.[9]

An extensive critical examination of my methods and results has been made by Prof. Curtis. His discussion and my reply have been published together in Bulletin No. 11 of the National Research Council.

Dr. Schouten has attempted to derive the distances of clusters by assuming that the frequency of absolute magnitude (the luminosity-curve) is the same in globular clusters and in the neighbourhood of the sun.[10] The method is questionable for several reasons: (1) All spectral types are lumped together by Schouten regardless of our present knowledge of the peculiar relation of type and luminosity in the globular clusters. (2) The giant-dwarf phenomenon is essentially ignored in the method. (3) The observed luminosity-curves in globular clusters do not conform with the law assumed.[11] (4) It is certainly improbable that the stage of evolution in any given cluster is closely comparable with the average of the many stages represented by the heterogeneous mixture around the sun. (5) As applied, the luminosity-curve method involves dangerous extrapolation, for we know the frequency of magnitudes for only the very brightest stars in clusters.[12]

Using the necessarily fragmentary luminosity-curves for a few clusters, Schouten finds distances averaging about one-eighth the values I have computed.

Recently, Kapteyn and van Rhijn published a valuable paper on the proper motions of Cepheid variable stars of the short-period sub-type.[13] It is generally accepted that Cepheid variables of long period are giant stars; and from the simultaneous occurrence of the long-period and short-period Cepheids in globular clusters,[14] I have assumed of course that the short-period Cepheids, which occur most frequently in clusters and serve in one of the methods of estimating the distances, are also giant stars. Kapteyn and van Rhijn, on the other hand, have computed, from the large values of the proper motion, small distances for the cluster-type variables, and therefore low luminosities. They conclude that Cepheid variables of this sub-type may be dwarfs, both near the sun and in clusters; and, by assuming that the long-period Cepheid variables in clusters are abnormalities and the short-period Cepheids are normal, they assert that the clusters may be at less than one-seventh the distances I place them. But Kapteyn and van Rhijn appear to have overlooked the decisive factor that the known radial velocities of these short-period Cepheids are remarkably high [15] (much too high, apparently, for the application of the method they use;[16] and therefore that the large proper motions they deduce and the wide distribution in galactic latitude are almost certainly the result of exceptionally high velocities in space, rather than an indication of nearness and low luminosity. Similarly, the long-period variables of spectral type M are giants at maximum, are widely distributed in galactic latitude, and have high space velocities.

As Dr. Crommelin has hinted recently in the *Observatory*,[17] a sufficient answer to those who would reduce the distance of clusters to one-fifth or one-tenth the values proposed, is that apparently they do not consider fully the dire consequences of such reduction on a vast body of other astronomical data that is now generally accepted. If the distances I give are not greatly reduced or increased these troubles do not arise; all that we know of the colours, spectra, magnitudes, and motions in the clusters, and of the clusters, then fits in well with our general stock of astronomical fact and theory.

Before we knew much about the character of stars in clusters we were not restricted by observation or theory from placing the clusters at whatever distances we liked. But now, if we alter the present distances by the amount Curtis, Schouten, and Kapteyn and van Rhijn suggest, we immediately set up peculiarities and discordances in great numbers. For example, among other difficulties evoked by such changes, we would seriously question the general applicability of the spectroscopic method of determining luminosities and distances;[18] we would introduce confusion into Russell's and Eddington's theories which now so happily conform with physical laws and observational results, in clusters as well as outside; we would overthrow the period-luminosity law of Cepheid variation. Sooner or later it may be necessary to divide or multiply by 1·5 (Dr. Crommelin suggests 2) the distances I have computed for the clusters; any larger factor will entail alterations elsewhere that now appear improbably large.

It seems to me that a better line of attack on the proposed scale of the Galaxy would be to question the apparent magnitudes rather than the absolute luminosities. The latter, as we have seen, are supported by too much evidence of a varied nature to yield easily. Moreover the values of the absolute luminosities for the stars in clusters come within the range of our usual experience, whereas the apparent magnitudes (and distances) of cluster stars are quite different from those of stars we ordinarily treat.

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[1] Continued from p. 547.

Since the computed distances depend equally on absolute and apparent magnitudes, they could be considerably changed, if the apparent magnitudes are widely wrong, without disturbing present ideas about stellar luminosity. The fundamental work on magnitude standards at Mount Wilson, Harvard, Greenwich, and elsewhere supply, however, a basis of unquestioned value for the cluster work. The apparent magnitudes I have observed in clusters cannot, I believe, be far wrong;[19] but has the light of these distant stars been reduced in transit so that the apparent magnitudes as observed are not a true index of distance? This question should be kept in mind, but the following points seem to show that the observed apparent magnitudes do not differ seriously from true apparent values because of a hypothecated diminution of light during its passage through space:

(1) The absence of measurable differential light scattering in space, which would appear as a dependence of star-colour on distance.

(2) The apparent restriction of known obstructing matter to regions near the planes of the local cloud and the Galaxy;[20] the globular clusters we study are practically all outside these regions.

(3) The diameter-magnitude correlation for globular clusters, which shows, almost without exception, that the globular clusters with large angular diameters are bright, and that the faint globular clusters are of small angular diameter.[21]

(4) The absence of observable proper motion for clusters, notwithstanding large space velocities.

INCIDENTAL RESULTS

In the course of the investigation on the scale of the galactic system a number of incidental contributions of general scientific interest have been made.

I. The great distances of globular clusters provide a much more sensitive test of the degree of selective scattering of light in space than was formerly available from the studies of the colour of nearby stars. Results from many clusters, including the most remote, agree in showing no certainly measurable effect of distance on colour. We conclude that much less than one per cent. of the starlight is scattered while travelling for one thousand years through space.[22] This result, which does not hold of course for some restricted nebulous regions, indicates the extreme vacuity of interstellar space.

II. This absence of a measurable effect of distance on colour contributes an additional fact of some interest with regard to the nature of light. It is direct observational evidence that the amplitude of the light pulses of different wave lengths has suffered no differential alteration while travelling for more than 100,000 years. The age of this incoming stellar radiation, compared with that of the radiation used in laboratory experiments, is uncommonly impressive.

III. In a more definitely quantitative manner we can again use the base line in space and in time afforded by the globular clusters to derive another property of radiation. The times of maxima of several short-period Cepheid variable stars in the globular cluster Messier 5 (distance 12,000 parsecs) have been measured concurrently with blue and yellow light. Within the errors of observation no difference for the two colours is found in the time of these stellar outbursts.[23] That is, in travelling for 40,000 years, radiation that differs in wave length by 20 per cent. differs in time of arrival at the earth by less than two minutes, if at all. This is equivalent to a difference of less than one millimetre in a distance of 5000 miles. Stated otherwise, blue and yellow light travel with the same velocity with an uncertainty of less than one part in ten thousand million.

IV. In still another way can we make valuable use of the long base line provided by the remote clusters. A considerable analysis of the distribution of spectral types among the giant stars shows no measurable difference for near and distant globular clusters. This strongly suggests of course that the nearest systems are not appreciably more advanced in their evolution; but because of the finite velocity of light and the great differences in distance, they are, in our records, nearly 200,000 years older than the farthest ones. With these globular clusters we can, in effect, examine the process of stellar evolution throughout an interval of 2000 centuries. We find no evidence of change in that interval of time.[24]

Now Eddington has shown that very conspicuous advances in the evolution of a giant star would occur in less than 50,000 years, if gravitation is the main source of radiant energy.[25] We are led to believe, therefore, that gravitational contraction is not the main source of the energy that maintains the radiation of stars; it appears that the energy must come from the atom, and probably is released in the course of the transformation of the chemical elements.

The evidence for a slow stellar evolution is strongly supported, I believe, by the existence of stars, which are still in their giant stage, in the open clusters that move along the galactic plane. Dimensions now assigned the galactic system are so large that a single oscillation of a cluster must require millions of years. In fact, a greater space scale for the Galaxy practically makes necessary a long time scale and a slow stellar development. The extreme slowness with which the periods of Cepheid variables change, as Eddington has pointed out, also demands the new source of energy.[26]

V. In this connexion it may be observed that the question of the dependence of the speed of evolution on mass for a giant star is probably answered observationally by the regularly occurring phenomenon in clusters of increasing blueness with decreasing brightness. The well-known investigations by Eddington and Jeans indicate that high absolute brightness is associated with great mass, but the theory is not definite in regard to the relative rates of evolution for different masses. From the clusters we would conclude that the greater the mass the slower the development.[27]

VI. The most luminous stars in globular clusters, the spectra of which, by the way, appear to have the "*c*-characteristics" which are associated with extraordinary brightness, are more concentrated to the centre than fainter stars. This condition independently supports the inference that the most luminous are the most massive stars.

VII. The remotest object for which a definite estimate of distance has yet been made is one of these faint globular clusters, N.G.C. 7006, for which a value of about 65,000 parsecs (more than 200,000 light-years) has been obtained, and checked by three or four different photometric methods. The most recent determination of its distance involved the discovery and study with the 100-inch reflector at Mount Wilson of Cepheid variables of the 19th apparent magnitude—the faintest periodic variable stars on record. It is likely that more remote objects, with distances as yet unmeasured, have been seen or photographed—possibly among the faintest spiral nebulæ or among the faint stars in the Milky Way.

VIII. A recent investigation of Cepheid variable stars in the Small Magellanic Cloud has shown that the very faintest variables have periods of less than one day.[28] This result, which permits the direct extension of the period-luminosity law to the short-period type of Cepheid, is further evidence of the high absolute luminosity of the kind of Cepheid variable which is most frequent in globular clusters.

IX. The proposal of a larger scale for the galactic system brings us face to face with the "island universe" theory of spiral nebulæ, which, with varying success, has for many years maintained that the spirals are other "universes" of stars—that they are galaxies comparable with our own, and that our Galaxy, seen from a sufficient distance, would appear as a spiral nebula. A theory of "comparable galaxies" immediately becomes very difficult to maintain along with the larger dimensions of the galactic system. In a paper published three years ago I discussed at some length this problem of external galaxies.[29] The conclusion reached at that time, that the nebulæ of the spiral family are probably neither galactic in size nor stellar in composition, has been strengthened rather than weakened by subsequent investigations, particularly by van Maanen's remarkable work on the motions in the brighter spirals.[30]

X. Since the brighter spiral nebulæ, according to the present view, are probably within the boundaries of our galactic system, it may be that the novæ occurring so frequently in the Andromeda nebula represent the encounter of this enormous, rapidly moving object with galactic stars. The suggestion is in harmony with the Seeliger-Monck hypothesis of the cause of ordinary nov ; andæ, moreover, it is in line with the only hypothesis that has yet been advanced to account for the peculiar irregular variable stars in the diffuse nebulæ, such as those in Orion.[31] This interpretation of the variables of the relatively near Orion nebula would certainly be of significance for historical geology, since disturbances of our sun, much less serious in character than those observed for novæ and for the Orion variables, would be of paramount importance in matters pertaining to terrestrial climates and organisms.[32]

XI. Conversely we can use the geological records to show that the radiating equilibrium of the sun probably has been uncommonly stable compared with that of many stars. The investigation at Harvard under Prof. Bailey's direction of the frequency of galactic novæ brought out the remarkable result that at least fifteen novæ, brighter than the tenth magnitude at maximum, have appeared every year during the last three decades.[33] If a frequency of even one-fifth that amount has been maintained throughout the hundreds of millions of years of approximately constant solar radiation (shown by the geological records), more novæ have occurred than there are known stars. Our sun, however, which has certainly escaped not only disasters of this kind but even much less serious disturbances, apparently moves in an uneventful region of space.

XII. The attractive and somewhat futile speculations on the probability of the occurrence of protoplasmic life and its slow evolution elsewhere in the sidereal system must, of course, take account of the frequency of these calamitous stellar outbursts that we call novæ.

In connexion with this attempt at a partial interpretation of galactic structure it might be well to emphasise the following points.

(1) Many of the fundamental laws and assumptions of physics are involved in this sidereal superstructure, so that developments in thought or observation, which hereafter greatly affect these laws and customary assumptions, may at the same time seriously disturb existing conceptions of the sidereal system.

(2) The complete elucidation of the source of stellar energy may bring with it modifications both in our views of the evolution of stars and in our assumption of the importance of gravitational organisation of stellar bodies.

(3) The question of the obstruction of light in space is not in a satisfactory condition, and the nature of the radiation of the diffuse nebulæ is little understood; we have essentially no information concerning the pre-giant stage of stars and its relation to the diffuse nebulæ, and the dust and gases in space.

(4) Cepheid variables, though comparable with each other, may possibly be sufficiently different from other stars that we cannot use their speed of evolution as a quantitative measure of the speed of evolution for all stars.

For the present I take little heed of these warnings, and merely record them as examples of underlying uncertainties. They serve to remind us that the conclusions are based not only on favourable observations and theory, but also on the absence (for the time being) of seriously unfavourable data.

REFERENCES.

8. *Lund Meddelanden*, Series 2, No. 19.

9. Bul. Nat. Research Council, No. 11, p. 174.

10. Proc. Acad. Sci. Amsterdam, 20, p. 1108 ; 21, p. 36.

11. *Mt. W. Contr.* 155, and 175, p. 11.

12. I first tried out the method six years ago (*Mt. W. Contr.* 116, p. 81), but abandoned it as wholly unsuited to the brighter stars in globular clusters. The Kapteyn luminosity curves for separate spectral types, however, may be of high value.

13. Bul. Ast. Inst. Neth., No. 8.

14. Kapteyn and van Rhijn state that eight Cepheids of long period are known in two globular clusters. In my paper from which they get their data (*Mt. W. Contr.* 151) I show that twelve long-period Cepheids occur in the five globular clusters Messier 3, 5, 13, 15, and Omega Centauri. Four of these clusters contain also large numbers of short-period Cepheids only one or two magnitudes fainter than the long-period Cepheids. Unpublished results obtained at Harvard show that long-period Cepheids occur in other globular clusters.

15. *Mt. W. Contr.* 153, *Mt. W. An. Rep.* for 1918, and elsewhere.

16. Russell, *Astroph. Jour.* 54, p. 140.

17. *Observatory*, May 1922.

18. Bul. Nat. Research Council, No. 11, p. 184, 190.

19. The photovisual magnitudes for Messier 11, however, are probably affected by a serious scale error ; the colour indices do not agree with the spectra subsequently determined (*Mt. W. Contr.* 120 and 228).

20. *Mt. W. Commun.* 62, p. 6 ; cf. also Hubble, *Mt. W. An. Rep.* for 1921, p. 251.

21. *Mt. W. Contr.* 115, p. 12, 152, p. 10, and 161, p. 13.

22. *Mt. W. Contr.* 156, p. 5.

23. *Harv. Bul.* 763.
24. *Mt. W. Contr.* 156, p. 5, and 157, p. 14.
25. *Zeits. für Physik*, 7, p. 390.
26. Mon. Not. R.A.S. 79, p. 19.
27. This conclusion may not hold for close double stars, as certain results from eclipsing binaries are not in full agreement; the less dense, dark companion is believed to be, frequently, less massive and also less developed than its primary.
28. *Harv. Bul.* 765; Proc. Nat. Acad. Sci. 8, p. 69.
29. Pub. Ast. Soc. Pac., October 1919.
30. *Mt. W. Contr.* 213 and 214.
31. *Mt. W. Contr.* 156, p. 12; cf. Graff, *Ast. Nach.* 5133.
32. *Jour. of Geol.* 29, p. 502.
33. The annual number brighter than the tenth magnitude actually exceeds forty, according to Bailey's data. Pub. Am. Ast. Soc. 4, p. 248.

Current Topics and Events.

In an article on Lord Inchcape's task in the *Sunday Times* of October 22, a former finance member of the Government of India, Lord Meston, makes an alarming suggestion. Speaking of things "useful, but not essential," he says "many of the research institutes and the like will come under the shears." The illiberal spirit which inspired our domestic wielders of the axe may thus be carried by one of them to India—a country which, more than any other, perhaps, has benefited by the application of science to "useful" purposes. The plant breeders there, alone, have literally added millions to the country's wealth; new wheats and cottons yielding 20 to 30 per cent more than the indigenous varieties have already been successfully introduced. It must not be forgotten that, in India, the prosperity of agriculture is a fundamental element of the solvency of the Government, for there, the State, as owner of the soil, takes one half of the rental value of the land. The sum thus raised approaches a moiety of the whole taxation of the country. It is to be hoped that such a suicidal policy as that indicated by Lord Meston will not be advocated by Lord Inchcape, though as a quondam member of the Geddes Committee he may be inclined to repeat its mistakes.

The French airman, M. Maneyrolle, won the prize of 1000*l.* offered by the *Daily Mail*, by a wind flight on October 21 lasting three hours and twenty-two minutes. The notable successes registered during the recent French contests, and especially during the German contests, raised the question whether British fliers could rival the feats of their foreign colleagues, and the offer of a prize of 1000*l.* by the *Daily Mail* led to the organisation, at Itford Hill and Firle Beacon on the South Downs, of the first British gliding contests since the war, which commenced on October 16 and continued through the week. Additional prizes were offered by the Royal Aero Club and others. The entry of British machines and pilots was very encouraging, there being some two score British fliers, besides foreign aviators, notably the Dutch airman, M. Fokker. A large number of short flights and some quite long flights were made; yet on the whole the results of the meeting were not of a sensational nature until the last day of the meeting. The general conclusion is that British aviators do not fall behind those of Germany, and that it is possible to find suitable arenas in this country for the practice and display of motorless flight. The most notable achievement of the first day of the contest was a thirty-seven-minute glide by M. Fokker, but this was surpassed by a fine flight executed by Mr. F. P. Raynham. This aviator had already taken a place in the front rank of British pilots in the recent air-race round England: he added to his laurels by remaining in the air in a motorless machine for one hour and fifty-three minutes, thus putting himself in the same category as the German record-makers, Martens and Hentzen. But on the last day, Saturday, two world-records were nevertheless established. J. R. Olley went up in a Fokker biplane, and remained in the air with a passenger for forty-nine minutes, while M. Maneyrolle, in a tandem monoplane glider, succeeded in remaining in the air for three hours twenty-two minutes, thus winning the *Daily Mail* prize and beating the previous record, that of Hentzen, by twelve minutes. During the last ninety minutes of his flight, M. Maneyrolle was accompanied by a monoplane glider flown by Squadron-Leader A. Gray, and it was night when the two machines landed within 100 yards of the point from which they started. These competitions on the South Downs will serve as an encouragement to motorless flight in this country, and will help in the accumulation of knowledge and experience on one of the most interesting developments in modern aeronautics.

The height of the ground at Firle Beacon, where the gliding competition referred to in the foregoing paragraph was held, is 718 feet above sea level, and it slopes downwards somewhat to Itford Hill, which is situated about three miles to the westward. The gliding was chiefly from one or other of these positions. The meteorological conditions during the week could not be considered altogether favourable, and there was wide difference in the weather on the several days. At times the winds were too boisterous and unsteady for gliding, while at others the gliding was hampered by winds which were too light or by cloud and mist; the direction of the wind was chiefly from between north and east. On the closing day, Saturday, the surface wind was blowing at the rate of about 20 to 30 miles an hour, and M. Maneyrolle, in his record flight, kept mostly at about 200 feet above ground. The controlling conditions of the weather were similar throughout the week; a region of high barometer was situated to the north of Scotland and a region of low barometer was fairly stationary over the north of Spain. All who took part in the gliding contest, however, would know well what different weather could be experienced with similar controlling conditions.

At a meeting of manufacturers held on October 18 at the Institution of Electrical Engineers it was unanimously agreed, in view of the approval of the Postmaster-General to the memorandum and articles of association of the British Broadcasting Company having been obtained, to proceed with the registration of the company. The capital of the company,